



# Novel Co 20 Cr 15 Fe 26 Mn 17 Ni 22 ultra-fine grained high-entropy alloy

Michal Mroz, Anna Fraczekiewicz, Andras Borbely

## ► To cite this version:

Michal Mroz, Anna Fraczekiewicz, Andras Borbely. Novel Co 20 Cr 15 Fe 26 Mn 17 Ni 22 ultra-fine grained high-entropy alloy . Ecole thématique Métallurgie Mécanique, Oct 2016, Porquerolles, France. 2016. emse-01384988

**HAL Id: emse-01384988**

**<https://hal-emse.ccsd.cnrs.fr/emse-01384988>**

Submitted on 20 Oct 2016

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

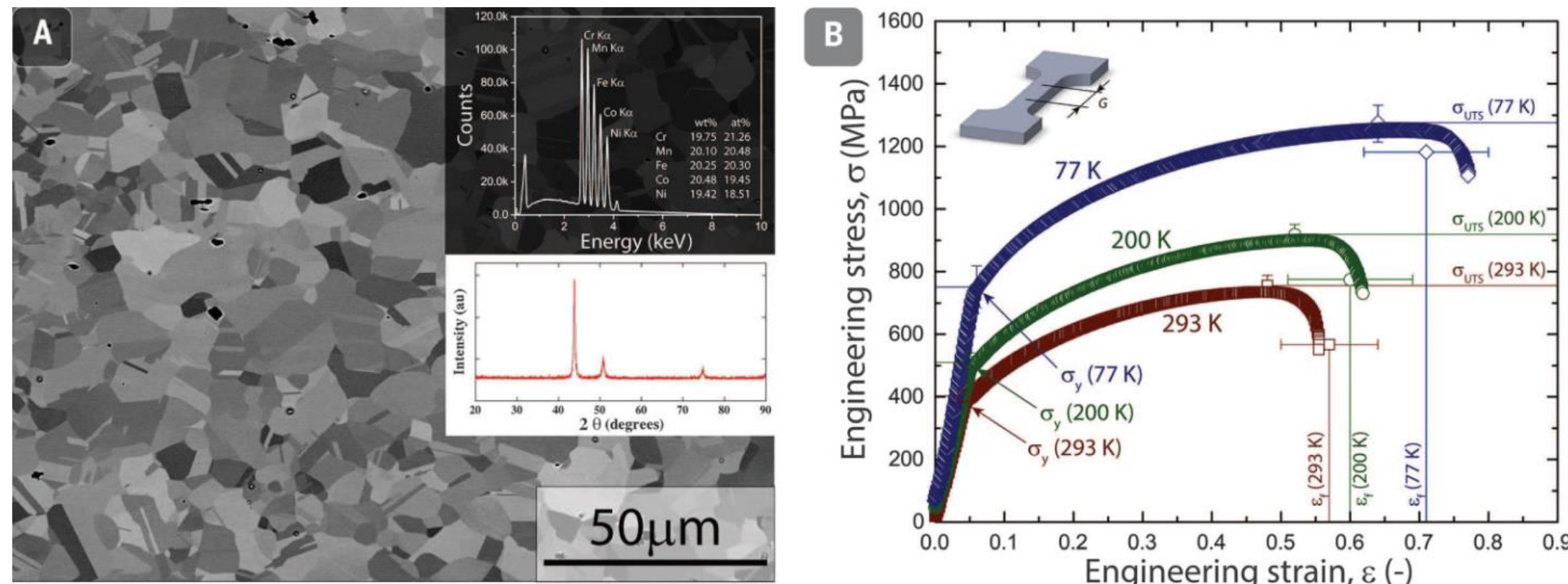
L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



## Origins of the alloy

### NOVEL COMPOSITION: based on equiatomic CoCrFeMnNi

- Reference alloy (Yeh, Cantor, 2004)
- Face-Centered Cubic structure (lattice parameter  $a = 3.6\text{\AA}$ )
- Yield strength of  $\sim 240\text{MPa}$  (recrystallized) and  $\sim 760\text{MPa}$  (cold-rolled)
- High ductility:  $>60\%$

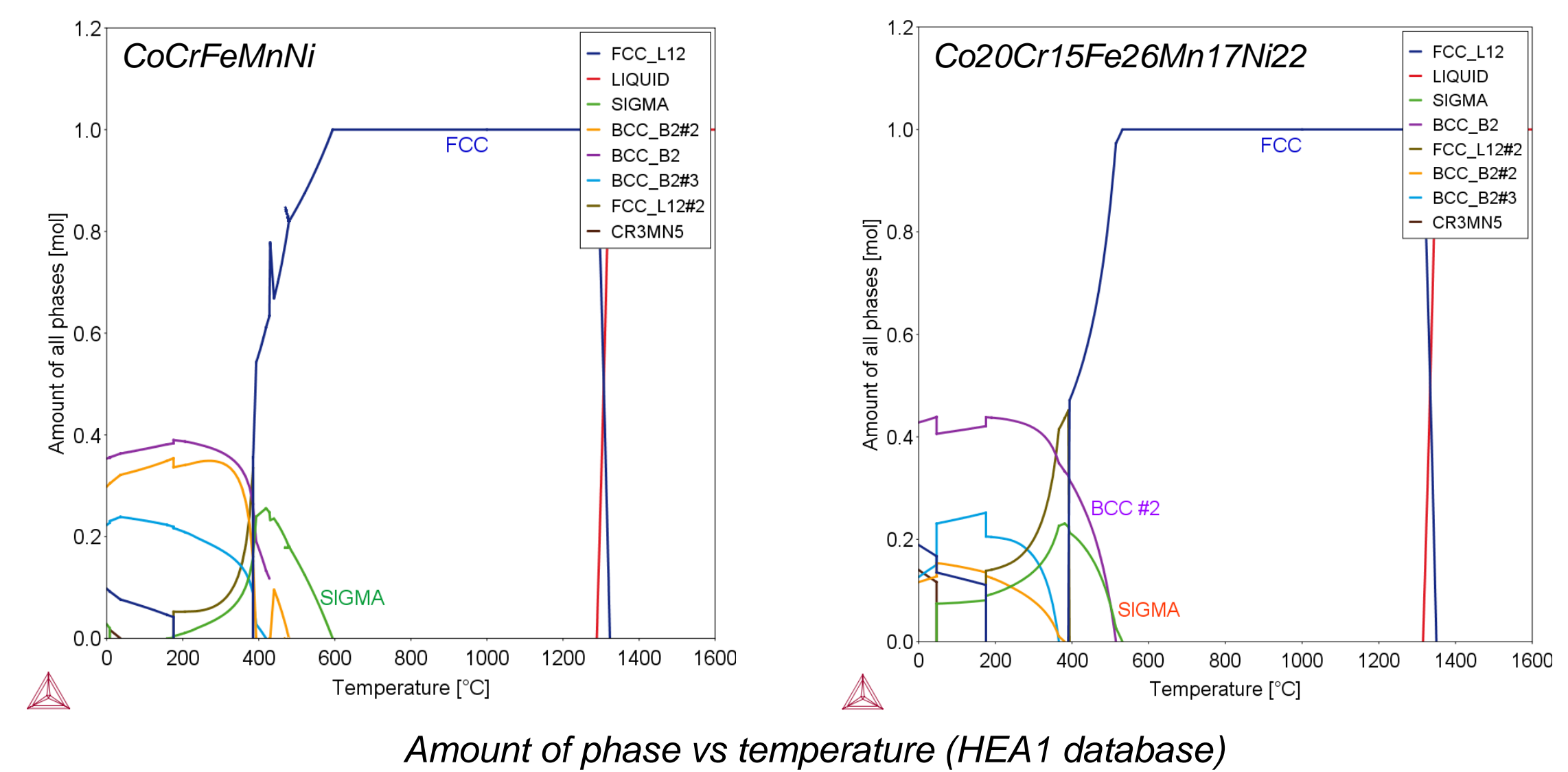


Recrystallized structure and stress-strain curves of CoCrFeMnNi, Gludovatz et al., 2014

- This composition was taken as a reference and optimized with Thermo-Calc software

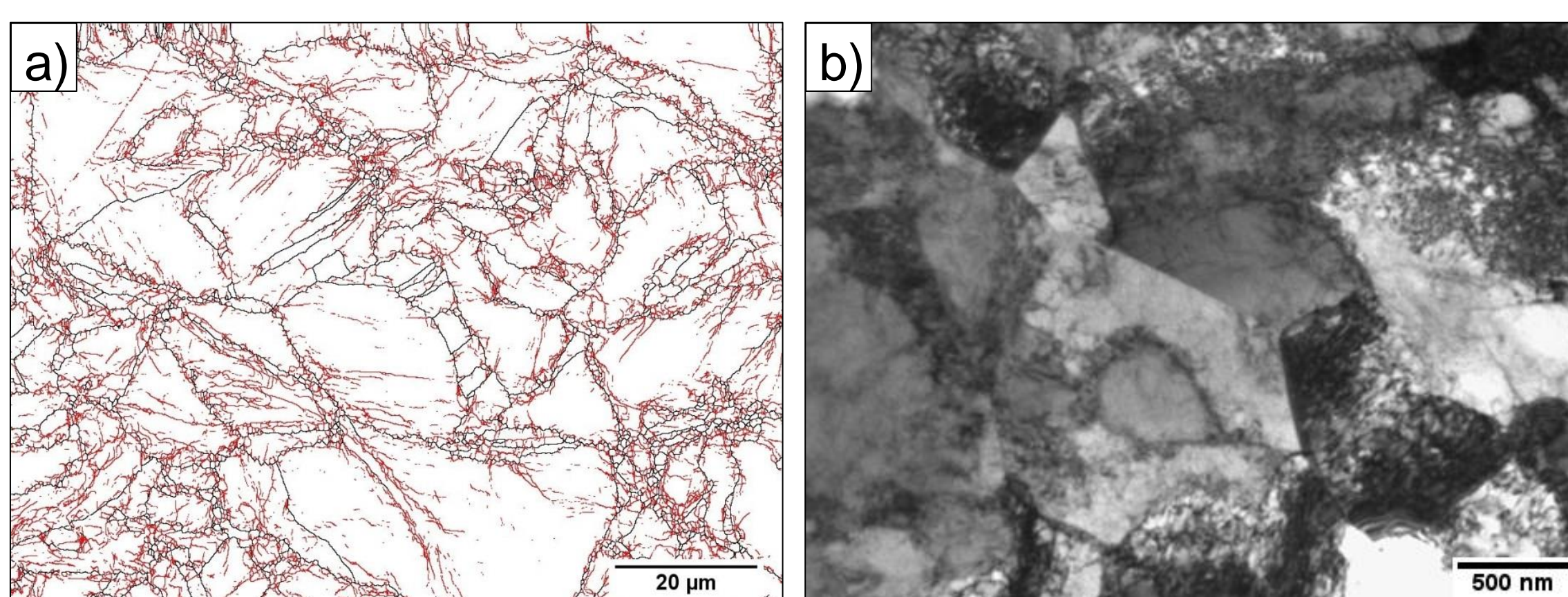
### THERMO-CALC : optimization of 'reference' equiatomic alloy

- FCC area increased to assure phase stability
- Intermetallics (especially  $\sigma$  phase) were avoided
- Amount of Cr decreased to lower temperature of phase transformations
- Amount of Ni increased (FCC stabilizing element)
- Novel alloy called A3S® : austenitic super stainless steel**



## Facility of nanostructuration

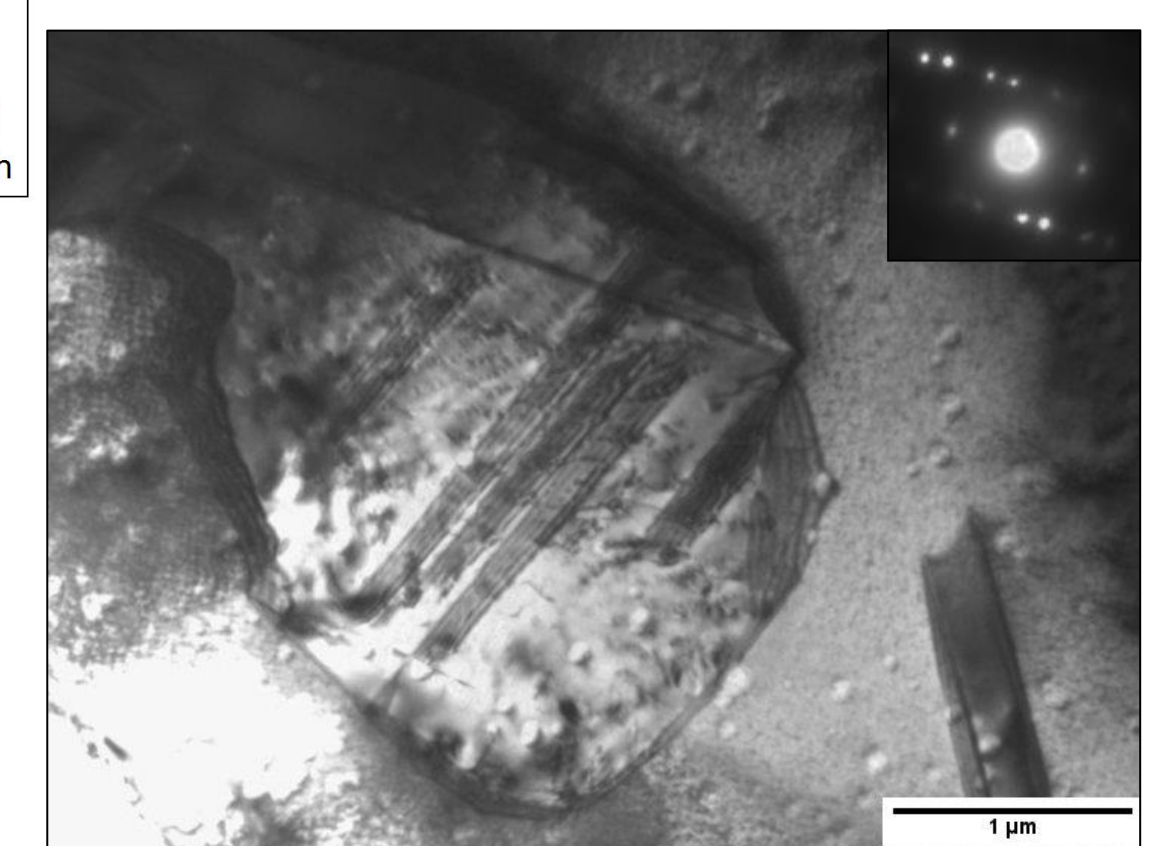
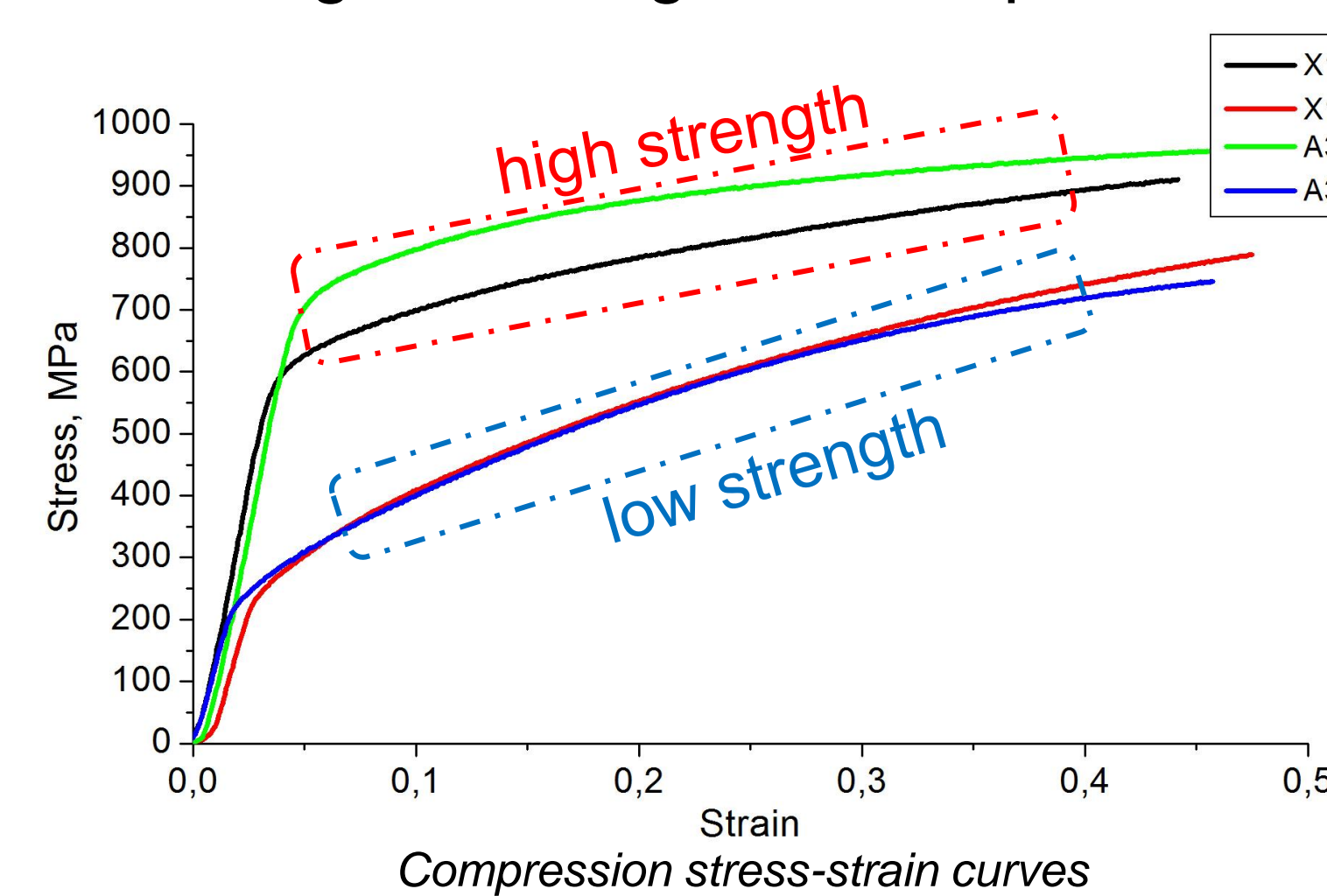
- After **hot forging**, nanostructure/UFG structure is formed in both alloys
- Many low-angle grain boundaries in grains, nanometric size of cells
- High density of dislocations



a) EBSD and b) TEM imaged of as-forged A3S

- After annealing (1000°C/2h) : only high-angle grain boundaries, high density of twins

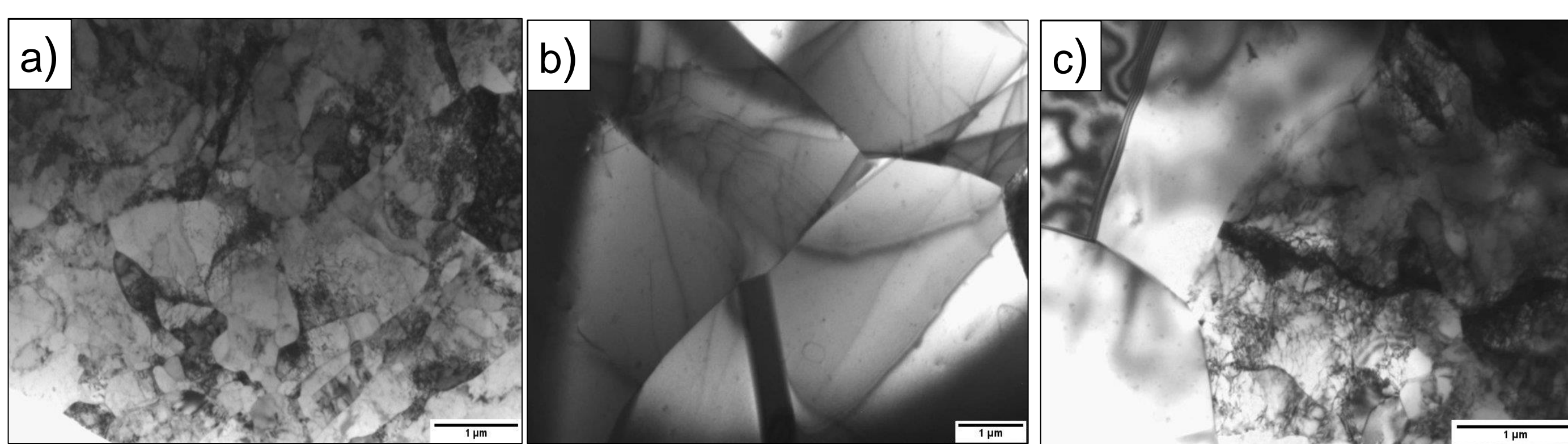
- Due to two different types of microstructure, two modes of deformation can be distinguished:
  - high strength**: high ( $\sim 750\text{MPa}$  for A3S and  $\sim 600\text{MPa}$  for X1) yield strength, low work hardening coefficient
  - low strength**: low ( $\sim 250\text{MPa}$ ) yield strength, high work hardening coefficient
- A3S has higher strength than equiatomic alloy; in X1 - nanotwins



TEM bright field images of as-forged X1

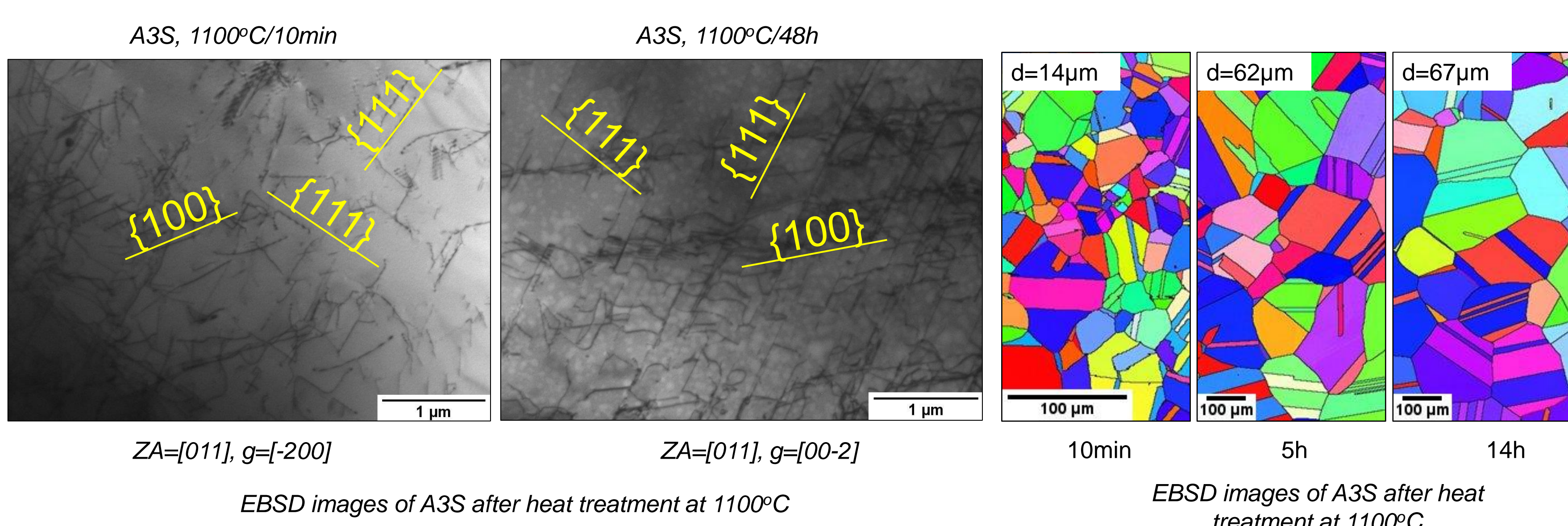
## Recovery and recrystallization phenomena

- Nanostructure is stable until  $\sim 700^\circ\text{C}$ , when the alloy loses its high strength properties
- Even after long heat treatment at  $600^\circ\text{C}$  (1 month), grains with dislocations cells are still present

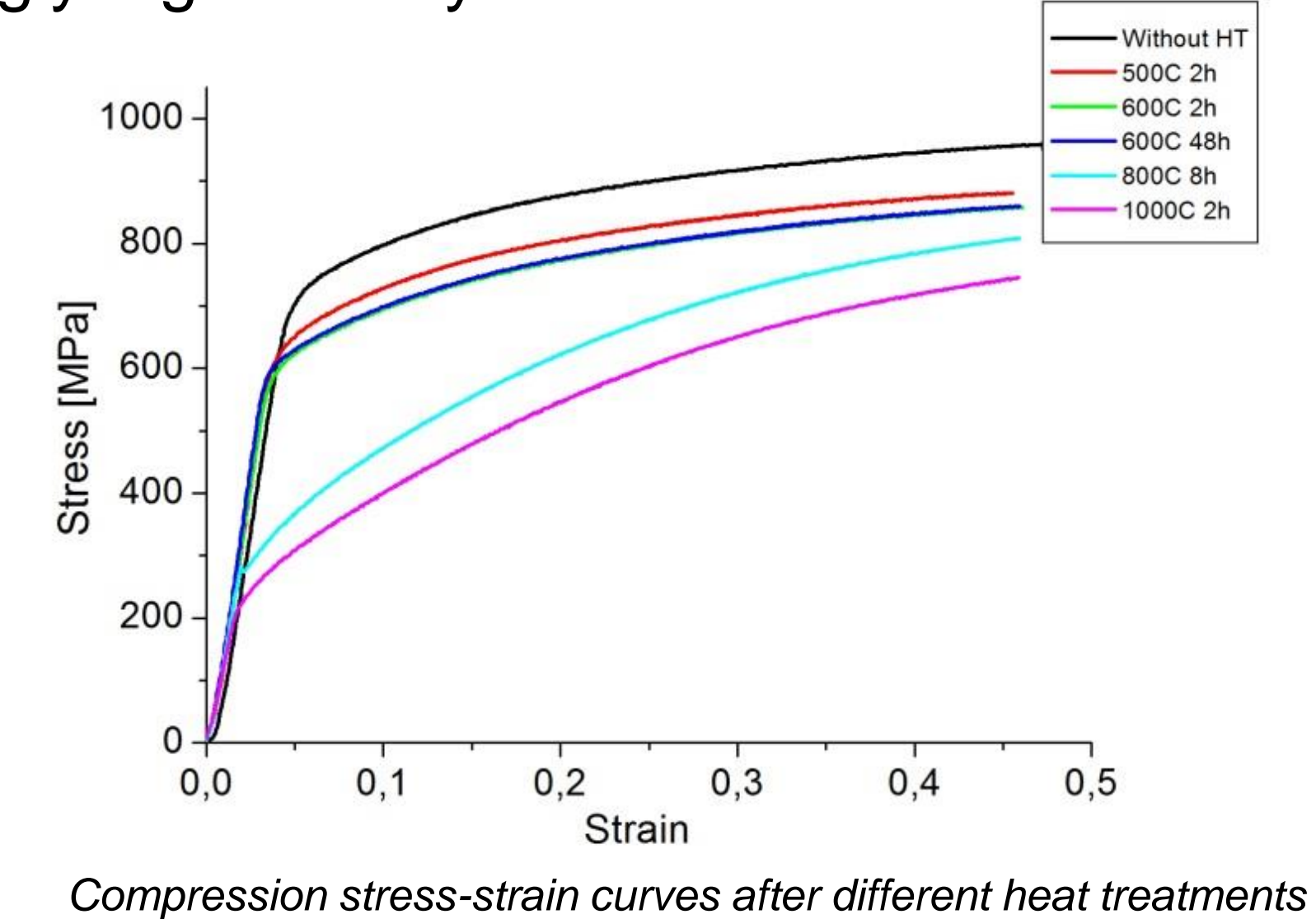


TEM bright field images of A3S annealed at: a)  $600^\circ\text{C}/48\text{h}$ , b-c)  $600^\circ\text{C}/1\text{ month}$

- High density of dislocations even after high T annealing (1000, 1100°C)
- Dislocations traces in characteristic planes:  $\{111\}$  and  $\{100\}$

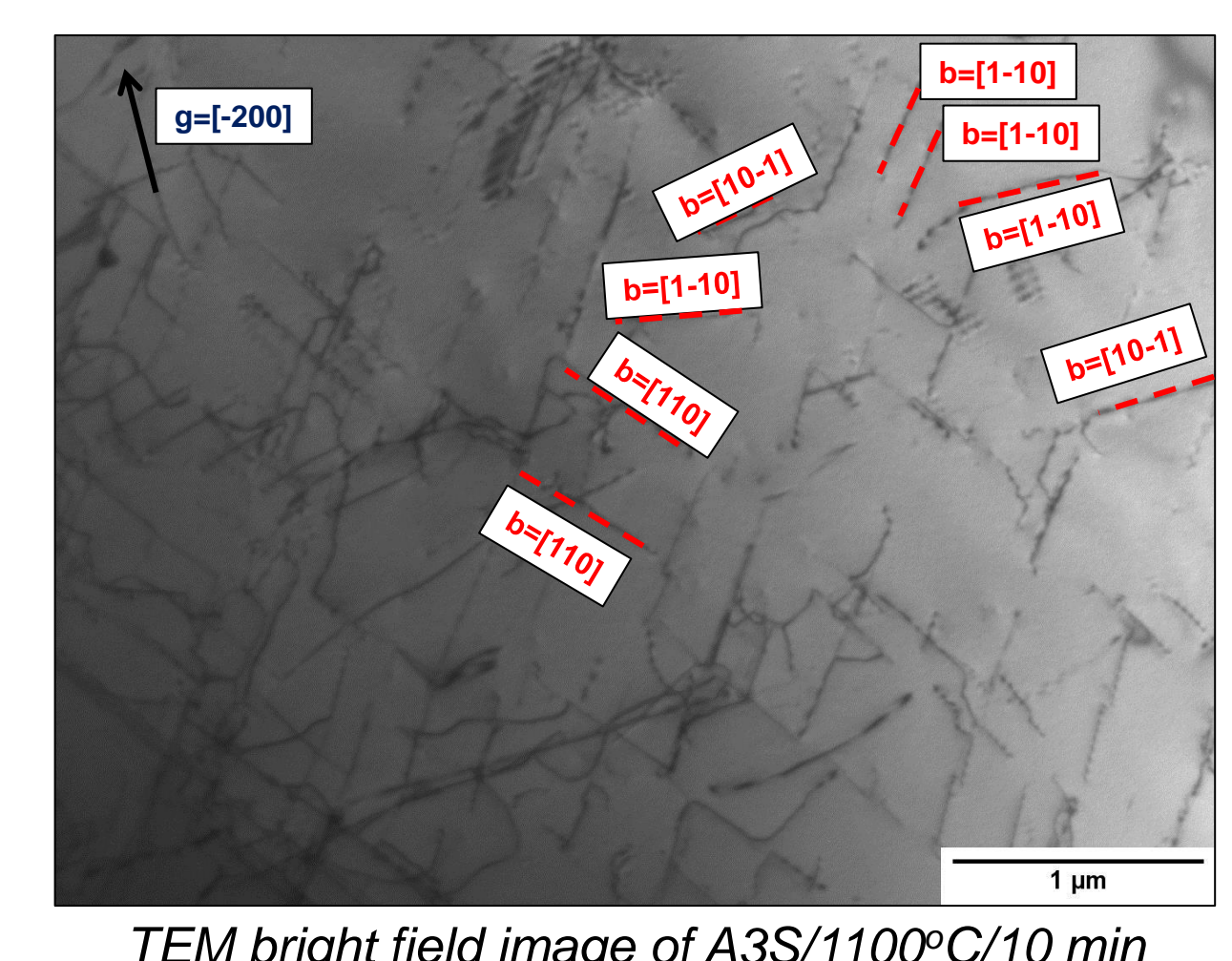


- After  $800^\circ\text{C}/8\text{h}$  annealing there are no substructures, grains with HAGB of few  $\mu\text{meters}$
- Surprisingly high density of dislocations



Compression stress-strain curves after different heat treatments

- Typical Burger vectors of type  $\langle 110 \rangle$  were observed
- Common for FCC metals



TEM bright field image of A3S/1100°C/10 min

## CONCLUSIONS

- New original composition A3S® was developed starting from equiatomic CoCrFeMnNi high-entropy alloy
- Comparing to reference composition, much higher (+150MPa) yield strength is achieved with similar elongation
- Easy formation of nanostuctures after hot forging
- Stable UFG structure until  $\sim 700^\circ\text{C}$
- Untypical phenomena of recovery/recrystallization:
  - grains free of dislocations after low T annealing
  - high density of dislocations after high T annealing